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NATIONAL EUTROPHICATION SURVEY

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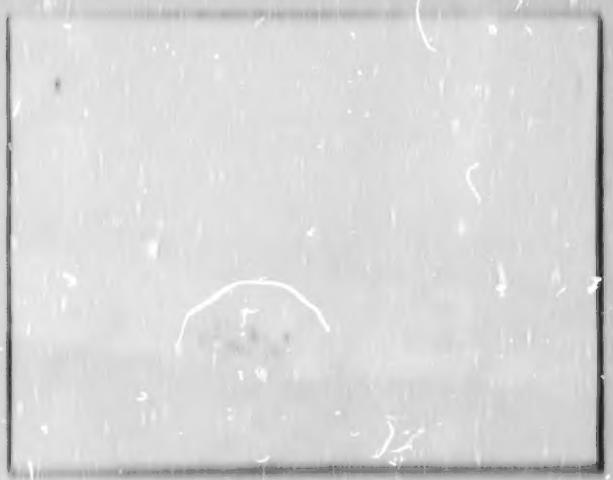

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16. ABSTRACT
Annual total phosphorus and total nitrogen loadings to the lake were estimated and subdivided according to either point or non-point source origin. An assessment of the lake's trophic condition and limiting nutrient is also provided. All data collected by the U.S.E.P.A. National Eutrophication Survey during the one year study of the lake and its tributaries are included in the report.

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REPORT

ON

NORFORK LAKE

BAXTER AND FULTON COUNTIES, ARKANSAS

OZARK COUNTY, MISSOURI

EPA REGION VI

WORKING PAPER No. 491

WITH THE COOPERATION OF THE

ARKANSAS DEPARTMENT OF POLLUTION

CONTROL AND ECOLOGY

AND THE

ARKANSAS NATIONAL GUARD

JANUARY, 1977

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REPORT ON NORFORK LAKE

BAXTER AND FULTON COUNTIES, ARKANSAS

OZARK COUNTY, MISSOURI

EPA REGION VI

by

National Eutrophication Survey

Water and Land Monitoring Branch
Monitoring Applications Laboratory
Environmental Monitoring & Support Laboratory
Las Vegas, Nevada

and

Eutrophication Survey Branch
Corvallis Environmental Research Laboratory
Corvallis, Oregon

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FOREWORD

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to freshwater lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point source discharge reduction and nonpoint source pollution abatement in lake watersheds.

ANALYTIC APPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed.

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader based correlations between nutrient concentrations (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's freshwater lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by the U.S. Environmental Protection Agency and to augment plans implementation by the states.

ACKNOWLEDGMENTS

The staff of the National Eutrophication Survey (Office of Research and Development, U.S. Environmental Protection Agency) expresses sincere appreciation to the Arkansas Department of Pollution Control and Ecology for professional involvement, to the Arkansas National Guard for conducting the tributary sampling phase of the Survey, and to those Arkansas wastewater treatment plant operators who provided effluent samples and flow data.

The staff of the Water Division of the Arkansas Department of Pollution Control and Ecology provided invaluable lake documentation and counsel during the Survey, reviewed the preliminary reports and provided critiques most useful in the preparation of this Working Paper series.

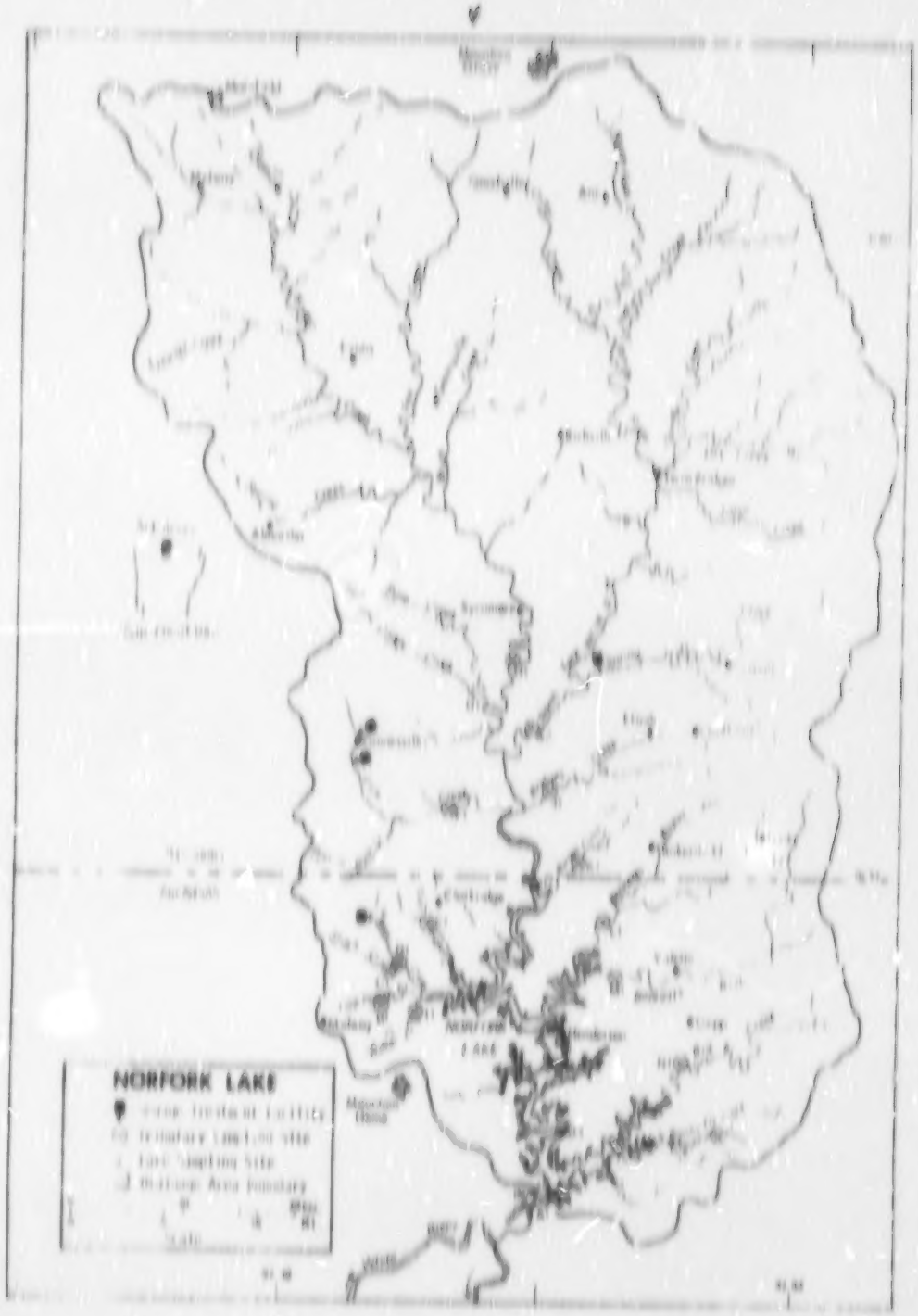
Major General Thomas C. Armstrong, the Adjutant General of Arkansas, and Project Officer Colonel Lavaun M. James, who directed the volunteer efforts of the Arkansas National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF ARKANSAS

LAKE NAME	COUNTY
Beaver	Benton, Carroll, Washington
Blackfish	Crittenden, St. Francis
Blue Mountain	Logan, Yell
Bull Shoals	Baxter, Boone, Marion (Taney, Ozark in MO)
Catherine	Garland, Hot Spring
Chicot	Chicot
DeGray	Clark, Hot Spring
Erling	Lafayette
Grand	Chicot
Greer's Ferry	Van Buren, Cleburne
Hamilton	Garland
Millwood	Hempstead, Howard, Little River, Sevier
Nimrod	Perry, Yell
Norfork	Baxter, Fulton (Ozark in MO)
Ouachita	Garland, Montgomery
Table Rock	Boone, Carroll (Barry, Taney in MO)


NORFORK LAKE

REPORT ON NORFORK LAKE, ARKANSAS
STORET NO. 0513

I. CONCLUSIONS

A. Trophic Condition:*

Based upon field observations and Survey data, Norfork Lake is considered mesotrophic. Potential for primary production as indicated by algal assay control yield was low. Chlorophyll a values ranged from a low of 0.3 µg/l in the summer to a high of 16.4 µg/l with a mean of 3.4 µg/l. The mean Secchi disc reading was 144 cm (57 inches). Of the 16 Arkansas lakes sampled in 1974, 12 had greater median total phosphorus levels, 5 had greater median inorganic nitrogen values, and 12 had greater median dissolved orthophosphorus levels than Norfork Lake.

There was near oxygen depletion in Stations 01 to 06 of the lake during the September and October sampling rounds. Survey limnologists noted hydrogen sulfide in bottom samples at Stations 01, 02, 03, and 06 during these rounds.

B. Rate-Limiting Nutrient:

Algal assay results indicate that Norfork Reservoir is limited by available phosphorus. Spikes with phosphorus alone or nitrogen and phosphorus simultaneously resulted in

*See Appendix E

increased assay yields. The addition of nitrogen alone did not produce a growth response. The ratios of total available nitrogen to orthophosphorus (N/P) in the lake data further substantiate phosphorus limitation.

C. Nutrient Controllability:

1. Point sources -

The mean annual phosphorus load from point sources was estimated to be 3.8% of the total load reaching Norfork Lake. The city of Gainesville contributed 1.6% of the total load. In addition, there are two trout hatcheries, Bryans Springs Trout Farm and Crystal Lake Fisheries that discharge into Bryant and Hunter Creeks, respectively (Missouri Department of Natural Resources, manuscript). Nutrient contributions from these sources are not known.

Loading calculations based upon nutrient concentrations and flow data yield a net export of phosphorus from Norfork Lake, suggesting that sampling was not adequate to depict actual loading and export rates. This export could be attributed to undetected discharges reaching the lake from unknown industrial and municipal sources. Additional sampling and an evaluation of current land use and lakeshore construction are required before a nutrient budget for the lake can be determined.

2. Nonpoint sources -

The total phosphorus load from nonpoint sources accounted for 98.4% of the loading reaching Norfork Lake. Major tributaries contributed 80.4% for the total while minor tributaries and ungaged drainage areas contributed 18.4%.

Norfork Lake has localized problem areas related to runoff and seepage from developed areas having inadequate sewage treatment facilities and runoff from agricultural leases (Arkansas Department of Pollution Control and Ecology, 1971). This runoff contributed to high coliform bacterial counts and enrichment around the Pigeon Creek drainage area and Cranfield. The coliform bacteria counts at five of the sampling points of the Pollution Control Survey exceeded the maximum set forth by the Arkansas State Health Department.

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS

Lake and drainage basin characteristics are itemized below. Lake morphometry was provided by the Arkansas Department of Pollution Control and Ecology. Tributary flow data were provided by the Arkansas District Office of the U.S. Geological Survey (USGS). Outlet drainage area includes the lake surface area. Mean hydraulic retention time was obtained by dividing the lake volume by the mean flow of the outlet. Tributary 0513 Q-1 is included in the drainage area and discharge figures for Station 0513 F-1, so has been omitted as an additional input to the lake. Precipitation values are estimated by methods as outlined in National Eutrophication Survey (NES) Working Paper No. 175. A table of metric/English conversions is included as Appendix A.

A. Lake Morphometry:

1. Surface area: 89.03 km^2.
2. Mean depth: 17.3 meters.
3. Maximum depth: 57.3 meters.
4. Volume: 1,543,096 x 10^6 m^3.
5. Mean hydraulic retention time: 355 days.

B. Tributary and Outlet:
(See Appendix B for flow data)

1. Tributaries -

Name	Drainage area (km²)	Mean flow (m³/sec)
A-2 North Fork White River	1,460.8	19.61
C-1 Hutch Creek	22.8	0.23
D-1 Pigeon Creek	23.1	0.24
E-1 East Pigeon Creek	24.9	0.26
F-1 Lick Creek	205.9	1.62
G-1 Pine Creek (Caney Creek)	106.4	0.78
H-1 Bryant Creek	1,349.4	14.10
J-1 Bridges Creek	75.1	0.55
K-1 Barren Creek	26.9	0.20
L-1 Bennetts Bayou	174.0	1.03
M-1 Bennetts River	176.6	1.05
N-1 Big Creek	126.2	1.42
P-1 Brushy Creek	33.2	0.34
Minor tributaries and immediate drainage -	727.4	7.16
Totals	4,593.6	50.25
2. Outlet - A-1 North Fork White River	4,682.7	50.25

C. Precipitation:

1. Year of sampling: 150.9 cm.
2. Mean annual: 140.8 cm.

III. LAKE WATER QUALITY SUMMARY

Norfork Lake was sampled four times during the open-water season of 1974 by means of a pontoon-equipped Huey helicopter. Each time, samples for physical and chemical parameters were collected from seven stations on the lake and from a number of depths at each station (see map, page 9). During each visit, depth-integrated samples were collected from each station for chlorophyll a analysis and phytoplankton identification and enumeration. During the first and last visits, 18.9-liter depth-integrated samples were composited for algal assays. Maximum depths sampled were 57.3 meters at Station 01, 33.5 meters at Station 02, 51.8 meters at Station 03, 40.8 meters at Station 04, 31.7 meters at Station 05, 31.4 meters at Station 06, and 13.1 meters at Station 07. For a more detailed explanation of NES methods, see NES Working Paper No. 175.

The results obtained are presented in full in Appendix C and are summarized in III-A for waters at the surface and at the maximum depth for each site. Results of the phytoplankton counts and chlorophyll a determinations are included in III-B. Results of the limiting nutrient study are presented in III-C.

B. Biological Characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Algal Units per ml
04/05/74	1. Chroomonas	554
	2. Melosira	408
	3. Stephanodiscus	148
	4. Centric diatoms	74
	5. Cryptomonas	74
	Other genera	149
	Total	1,409
06/19/74	1. Fragilaria	645
	2. Dinobryon	609
	3. Cryptomonas	179
	4. Ceratium	72
	5. Cyclotella	72
	Other genera	214
	Total	1,791
09/03/74	1. Fragilaria	805
	2. Nitzschia	689
	3. Microcystis	612
	4. Achnanthes	402
	5. Melosira	345
	Other genera	1,323
	Total	4,196
10/10/74	1. Microcystis	603
	2. Flagellates	362
	3. Cryptomonas	327
	4. Dactylococcopsis	241
	5. Rhogostis	201
	Other genera	1,168
	Total	2,897

2. Chlorophyll a -

Sampling Date	Station Number	Chlorophyll a (ug/l)
04/05/74	01	3.0
	02	2.4
	03	2.2
	04	2.4
	05	16.4
	06	2.8
	07	0.8
06/19/74	01	0.3
	02	1.3
	03	0.4
	04	1.1
	05	2.1
	06	2.5
	07	3.8
09/03/74	01	3.6
	02	2.7
	03	3.6
	04	3.9
	05	3.3
	06	5.1
	07	7.7
10/10/74	01	2.0
	02	2.3
	03	2.3
	04	3.3
	05	3.6
	06	3.8
	07	7.1

C. Limiting Nutrient Study:

1. Autoclaved, filtered, and nutrient spiked -

a. 04/05/74 - Stations 01-03

Spike(mg/l)	Ortho P Conc.(mg/l)	Inorganic N Conc.(mg/l)	Maximum Yield (mg/l-dry wt.)
Control	0.005	0.275	0.1
0.05 P	0.055	0.275	6.4
0.05 P + 1.0 N	0.055	1.275	12.1
1.00 N	0.005	1.275	0.1

b. 10/09/74 - Stations 01-04

Spike(mg/l)	Ortho P Conc.(mg/l)	Inorganic N Conc.(mg/l)	Maximum Yield (mg/l-dry wt.)
Control	0.010	0.082	0.2
0.05 P	0.060	0.082	1.7
0.05 P + 1.0 N	0.060	1.082	19.6
1.00 N	0.010	1.082	0.2

c. 10/09/74 - Stations 05-07

Spike(mg/l)	Ortho P Conc.(mg/l)	Inorganic N Conc.(mg/l)	Maximum Yield (mg/l-dry wt.)
Control	0.015	0.157	0.5
0.05 P	0.065	0.157	4.5
0.05 P + 1.0 N	0.065	1.157	18.4
1.00 N	0.015	1.157	0.3

2. Discussion -

The control yields of the assay alga, Selenastrum capricornutum, indicate that the potential for primary productivity was low to moderate on Norfork Reservoir during the spring and fall sampling periods. The lake was phosphorus limited at those times as indicated by the increased yield of the test alga in response to an addition of orthophosphorus. Spikes

with nitrogen and phosphorus simultaneously resulted in maximum yield. Spikes with nitrogen alone did not produce a response beyond the control yield.

The spring assay sample for Stations 04 to 07 was broken during shipment, so is not included in this report.

The mean N/P ratios were 77/1 in the spring, 59/1 in the summer, 38/1 in the early fall, and 33/1 in the late fall, further suggesting primary limitation by phosphorus. An N/P ratio of 14/1 or greater generally reflects phosphorus limitation.

IV. NUTRIENT LOADINGS
(See Appendix D for data)

For the determination of nutrient loadings, the Arkansas and Missouri National Guards collected monthly near-surface grab samples from each of the tributary sites indicated on the map (page v), except for the high runoff months of March and April when two samples were collected. Sampling was begun in June 1974, and was completed in May 1975.

Through an interagency agreement, stream flow estimates for the year of sampling and a "normalized" or average year were provided by the Arkansas and Missouri District Offices of the USGS for the tributary sites nearest the lake.

In this report, nutrient loads for sampled tributaries except Lick Creek, Station F-1, were determined by using a modification of a USGS computer program for calculating stream loadings. Nutrient loads indicated for tributaries are those measured minus known point source loads, if any.

Nutrient loadings for F-1, Lick Creek, and unsampled "minor tributaries and immediate drainage" ("ZZ" of USGS) were estimated by using the mean annual nutrient loads, in $kg/km^2/yr$, at Stations C-1, D-1, E-1, G-1, K-1, N-1, and P-1, and multiplying the means by the ZZ area in km^2.

Nutrient loads for the Gainesville, Ozark County School District, and Rainbow Trout and Game Ranch wastewater treatment plants were estimated at 1.134 kg P and 3.401 kg N/Capita/yr.

A. Waste Sources:

1. Known municipal -

Name	Population Served	Treatment	Mean Flow ($m^3/d \times 10^3$)	Receiving Water
Gainesville*	300	Stabilization pond	0.114**	Lick Creek
Ozark County School District R-5 (Gainesville)	240	Stabilization pond	0.091**	Lick Creek
Rainbow Trout and Game Ranch†	188	Stabilization pond	0.070**	Spring Creek

2. Known industrial -

Name	Product	Treatment	Mean Flow ($m^3/d \times 10^3$)	Receiving Water
Baxter Laboratories***	Pharmaceuticals	Extended Aeration	0.121	Walker Creek to Pigeon Creek

*U.S. EPA, 1971.
**Estimated at 0.3785 m^3/capita/day.
***Arkansas Department of Pollution Control and Ecology, 1975.
†Missouri Department of Natural Resources, manuscript.

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	kg P/yr	% of total
a. Tributaries (nonpoint load) -		
A-2 North Fork White River	8,630	40.5
C-1 Hutch Creek	80	0.4
D-1 Pigeon Creek	90	0.4
E-1 East Pigeon Creek	80	0.4
F-1 Lick Creek	770	3.5
G-1 Pine Creek (Caney Creek)	265	1.2
H-1 Bryant Creek	4,955	22.7
J-1 Bridges Creek	170	0.8
K-1 Barren Creek	105	0.5
L-1 Bennetts Bayou	575	2.6
M-1 Bennetts River	765	3.5
N-1 Big Creek	415	1.9
P-1 Brushy Creek	115	0.5
b. Minor tributaries and immediate drainage (nonpoint load) -	2,180	10.0
c. Known municipal STP's -		
Gainesville	340	1.6
Ozark School District	270	1.2
Rainbow Trout and Game Ranch	210	1.0
d. Septic tanks* -	30	0.1
e. Known industrial -		
Baxter Laboratories	Unknown	---
f. Direct precipitation** -	1,560	7.5
Totals	21,805	100.0
C. Output - A-1 North Fork White River	27,040	
D. Net annual P export*** -	6,035	

*Estimate based on 30 lakeside residences, 21 parks, and 1 camp.
**Estimated (see NES Working Paper No. 175).
***Export probably due to unknown sources and/or sampling error.

C. Annual Total Nitrogen Loading - Average Year:

1. Inputs -

Source	kg N/yr	% of total
a. Tributaries (nonpoint load) -		
A-2 North Fork White River	704,060	42.3
C-1 Hutch Creek	5,215	0.3
D-1 Pigeon Creek	5,270	0.3
E-1 East Pigeon Creek	5,725	0.3
F-1 Lick Creek	67,045	4.0
G-1 Pine Creek (Caney Creek)	23,995	1.4
H-1 Bryant Creek	360,365	21.6
J-1 Bridges Creek	16,053	1.0
K-1 Barren Creek	9,150	0.6
L-1 Bennetts Bayou	64,010	3.8
M-1 Bennetts River	65,170	3.9
N-1 Big Creek	37,360	2.3
P-1 Brushy Creek	10,035	0.6
b. Minor tributaries and immediate drainage (nonpoint load) -	190,580	11.5
c. Known municipal STP's -		
Gainesville	1,020	0.1
Ozark School District	815	0.1
Rainbow Trout and Game Ranch	630	<0.1
d. Septic tanks* -	1,130	0.1
e. Known industrial -		
Baxter Laboratories	Unknown	---
f. Direct precipitation** -	96,115	5.8
Totals	1,664,340	100.0
2. Output - A-1 North Fork White River	1,442,945	
3. Net annual N accumulation -	221,395	

*Estimate based on 30 lakeside residences, 21 parks, and 1 camp.
**Estimated (see NES Working Paper No. 175).

D. Mean Annual Nonpoint Nutrient Export by Subdrainage Area:

Tributary	kg P/km²/yr	kg N/km²/yr
North Fork White River	6	482
Hutch Creek	4	229
Pigeon Creek	4	220
East Pigeon Creek	3	230
Lick Creek	3	262
Pine Creek (Caney Creek)	2	226
Bryant Creek	4	267
Bridges Creek	2	214
Barren Creek	4	340
Bennetts Bayou	3	166
Bennetts River	4	271
Big Creek	3	277
Brushy Creek	3	362

E. Mean Nutrient Concentration in Ungaged Streams:

Tributary	Mean Total P (mg/l)	Mean Total N (mg/l)
B-1 Little Pigeon Creek	0.019	1.430
T-1 Walker Creek	0.016	0.900

The mean nutrient concentrations to the above ungaged streams are in line with the levels in the unimpacted gaged tributaries entering Norfork Reservoir.

f. Yearly Loadings:

In the following table, the existing phosphorus annual loading is compared to the relationship proposed by Vollenweider (1975). Essentially, his eutrophic loading is that at which the receiving waters would become eutrophic or remain eutrophic; his oligotrophic loading is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A mesotrophic loading would be considered one between eutrophic and oligotrophic.

Note that Vollenweider's model may not apply to lakes with short hydraulic retention times or in which light penetration is severely restricted by high concentrations of suspended solids in the surface waters.

	Total Yearly Phosphorus Loading ($g/m^2/yr$)
Estimated loading for Norfork Lake	0.24
Vollenweider's eutrophic loading	0.80
Vollenweider's oligotrophic loading	0.40

V. LITERATURE REVIEWED

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VI. APPENDICES

APPENDIX A
CONVERSION FACTORS

CONVERSION FACTORS

Hectares x 2.471 = acres

Kilometers x 0.6214 = miles

Meters x 3.281 = feet

Cubic meters x 8.107×10^{-4} = acre/feet

Square kilometers x 0.3861 = square miles

Cubic meters/sec x 35.315 = cubic feet/sec

Centimeters x 0.3937 = inches

Kilograms x 2.205 = pounds

Kilograms/square kilometer x 5.711 = lbs/square mile

APPENDIX B

TRIBUTARY FLOW DATA

[illegible]

[illegible]

APPENDIX C

PHYSICAL AND CHEMICAL DATA

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	11	55	[illegible]	[illegible]		
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	11	55	[illegible]			5.6
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	11	55	[illegible]	[illegible]		
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	11	55	[illegible]	[illegible]		

[illegible]

[illegible]

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[illegible]

[illegible]

[illegible]						
[illegible]						
[illegible]						
[illegible]						

APPENDIX D

TRIBUTARY AND WASTEWATER TREATMENT PLANT DATA

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

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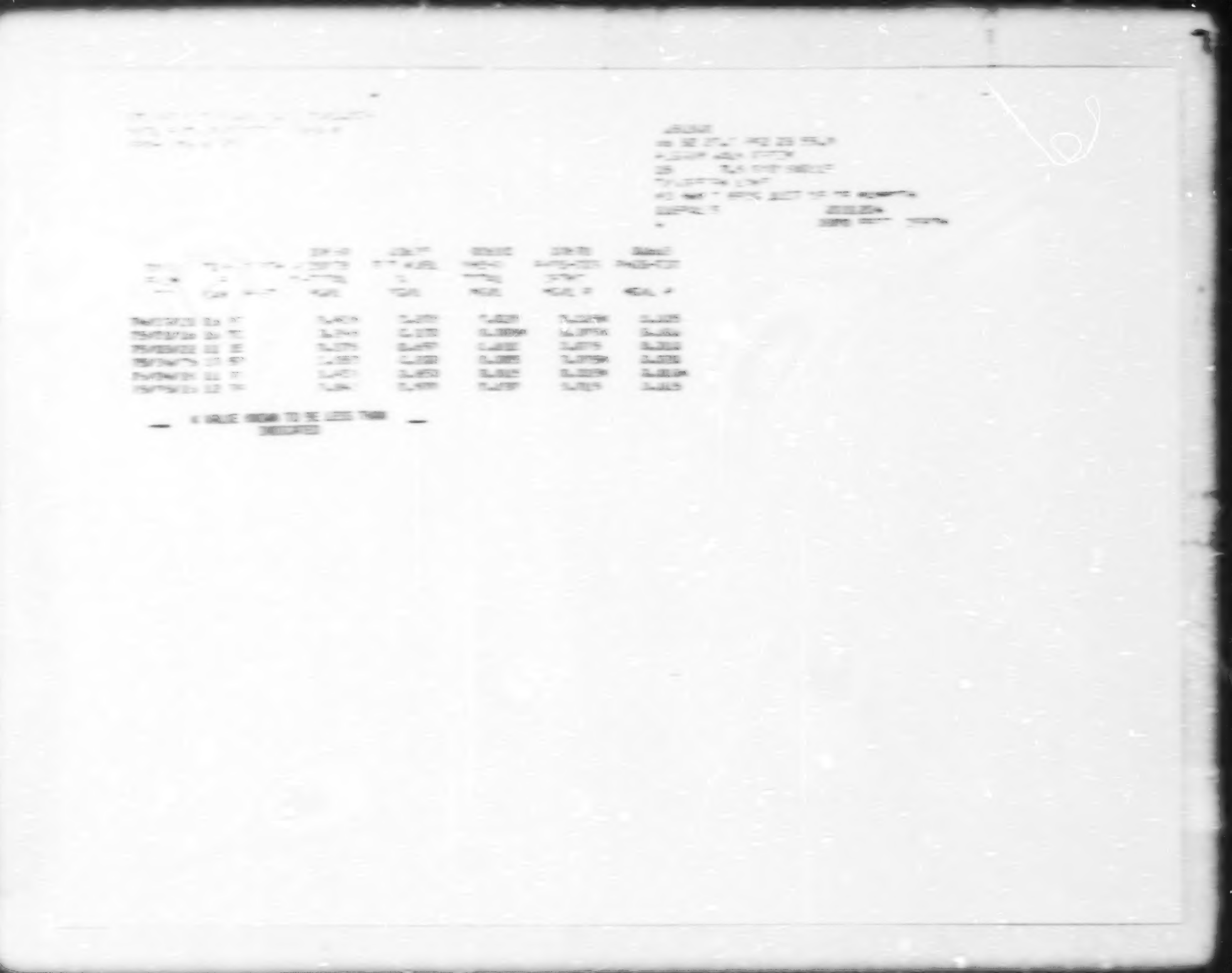
[illegible]

[illegible]



[illegible]

APPENDIX E

PARAMETRIC RANKINGS OF LAKES SAMPLED BY NES IN 1974

STATE OF ALABAMA